

## HIGH-POWER SEMICONDUCTOR LASER

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

[0001] The present invention relates generally to a high-power semiconductor laser, and particularly to a semiconductor laser having a specific structure of wave guide capable of heightening the output power thereof to reach that of the diffraction limit.

#### 2. The Prior Arts

[0002] Thanks to the matured technology of quantum well, the quantum-well semiconductor laser has been widely applied in various fields, particularly in the field of optical communication and storage. The semiconductor laser is advantageous in: high efficiency for electro-light conversion; applicable directly for electric-exciting; low cost; multiple options for materials; possible for simultaneously distributing in integrated circuits (ICs); minimized volume; and long lifetime.

[0003] However, since the saturated light intensity of a generic conventional semiconductor material is somewhat unsatisfactory to result in a relatively low output power (100mW maximum), an expensive bulky semiconductor laser is usually applied for pump solid-state laser, pump light source for optical fiber amplifier or Raman amplifier, surgical operation, and material processing.

### SUMMARY OF THE INVENTION

[0004] As mentioned above, the output power of a conventional semiconductor laser is usually relatively low in the case of a smaller output area because of low intensity of its saturated light, while, on the contrary, if the output area of the laser is expanded by broadening the waveguide thereof, a multi-mode light source could be resulted and the light intensity distribution is probably deteriorated to bring about the so-called catastrophic optical damage (COD). Hence; the present invention is proposed for the purpose of eliminating above defects.

[0005] In order to achieve the purpose, the present invention provides a high-power semiconductor laser fabricated by a usual process, in which the inclined

angle defined by the waveguide and interface is changed; the path of the waveguide is extended farther so that light wave propagates in the waveguide can be reflected in more times on reflective surfaces defined on the boundary between the waveguide and the light-emitting semiconductor unit to thereby secure a more objective statistical average of the laser light wave. Therefore, it is possible to obtain a better light-intensity distribution and an output power on a par with the diffraction limit when using the high-power semiconductor laser of the present invention.

[0006] The merits of the present invention may be summarized in the following:

[0007] (1) The output power could be raised up to 2W or more.

[0008] (2) The slope of close distribution is rather slow, unlike the filamentation phenomenon shown in the past and hence, light will not be concentrated locally and peak intensity can be lowered to alleviate COD under high power conditions.

[0009] (3) In the high-power semiconductor laser of the present invention, the wave guide in wave guide structure is broadened to 10 $\mu$ m up, such that an objective statistical intensity average and even output light distribution can be obtained.

[0010] For more detailed information regarding advantages or features of the present invention, at least an example of preferred embodiment will be described below with reference to the annexed drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The related drawings in connection with the detailed description of the present invention to be made later are described briefly as follows, in which:

[0012] Fig. 1 shows a schematic cutaway section of a first embodiment of a high-power semiconductor laser of the present invention;

[0013] Fig. 2 shows a schematic cutaway section of a second embodiment of the high-power semiconductor laser of the present invention;

[0014] Fig. 3 shows a schematic cutaway section of a third embodiment of the high-power semiconductor laser of the present invention;

[0015] Fig. 4 shows a schematic cutaway section of a fourth embodiment of the high-power semiconductor laser of the present invention;

[0016] Fig. 5 shows a schematic cutaway section of a fifth embodiment of the high-power semiconductor laser of the present invention;

[0017] Fig. 6 shows a schematic cutaway section of a sixth embodiment of the high-power semiconductor laser of the present invention;

[0018] Fig. 7 shows a schematic cutaway section of a seventh embodiment of the high-power semiconductor laser of the present invention;

[0019] Fig. 8 shows a schematic cutaway section of an eighth embodiment of the high-power semiconductor laser of the present invention;

[0020] Fig. 9 shows a schematic cutaway section of the high-power semiconductor laser of the present invention equipped with a ridge-structured waveguide;

[0021] Fig. 10 shows a schematic cutaway section of the high-power semiconductor laser of the present invention equipped with an external cavity;

[0022] Fig. 11 shows a curve illustrating the relationship between light power and current of the high-power semiconductor laser of the present invention without feedback light;

[0023] Fig. 12 shows the far-field distribution of the high-power semiconductor laser of the present invention before resonance;

[0024] Fig. 13 shows the optical spectrum of the high-power semiconductor laser of the present invention before resonance;

[0025] Fig. 14 shows the far-field distribution of the high-power semiconductor laser of the present invention after resonance;

[0026] Fig. 15 shows the optical spectrum of the high-power semiconductor laser of the present invention after resonance;

[0027] Fig. 16 shows a plotted curve illustrating the relationship between light and current of the high-power semiconductor laser of the present invention after resonance under feedback light provided by a mirror thereof;

[0028] Fig. 17A shows a lighted far-field full-range scanning chart of the high-power semiconductor laser of the present invention under feedback light after resonance;

[0029] Fig. 17B shows a lighted far-field scanning chart performed near a main projecting angle of the high-power semiconductor laser of the present invention under feedback light after resonance; and

[0030] Fig. 18 shows the near-field distribution with respect to the far-field distribution shown in Fig. 17A and 17B.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0031] Fig. 1 shows a schematic cutaway section of a first embodiment of a high-power semiconductor laser of the present invention. As shown in fig. 1, a waveguide structure (2) is formed in a light-emitting semiconductor unit (1). A waveguide (21) for transmitting light wave is formed in the waveguide structure (2), and a reflective surface (22) is prepared in the boundary between the waveguide (21) and the light-emitting semiconductor unit (1), in which every end of the waveguide (21) is extended to intersect a terminal of the light-emitting semiconductor unit (1) to form respective interfaces (23). In fig. 1, there are two interfaces (23) formed at where the waveguide (21) intersects the light-emitting semiconductor unit (1). These two interfaces have the functions of reflecting light wave and/or transmitting light wave.

[0032] The waveguide structure (2) is extended inwardly from an external side of the light-emitting semiconductor unit (1) such that an inclined angle  $\theta$  contained by the waveguide structure (2) and the normal of the interface (23) could be formed, in which the length  $L$  and width  $W$  of the waveguide structure (2) should satisfy the condition  $L \geq 2W/\tan\theta$ . The light wave emitted from the light-emitting semiconductor unit (1) is reflected by the interface (23) to enter the waveguide structure (2) again, and deflected (see dotted lines) at the reflective surface (22) repeatedly to thereby result in a preferred field distribution according to an average statistical effect, obtainable from the outputted light wave of a certain interface (23).

[0033] The foregoing inclined angle  $\theta$  may be as large to approach as  $90^\circ$  though,  $3-50^\circ$  is preferable when the practical space arrangement is put into consideration.

[0034] Fig. 2 shows a schematic cutaway section of a second embodiment of the high-power semiconductor laser of the present invention. As shown in fig. 2, an interface (23) of the waveguide (21) in the waveguide structure (2) is formed at each

of two terminals of the light-emitting semiconductor unit (1), in which an optimum deflection angle is defined in the waveguide (21), and an inclined angle between the waveguide (21) and the normal of a interface (23) is formed under the same condition as of the first embodiment. At this time, the total length of the waveguide structure (2) is longer than that in the first embodiment so that light waves are reflected in multiple times at the reflective surface (22) (represented by dotted path) to obtain a better field distribution of output light waves.

[0035] For extending the total length of the waveguide structure (2) in order to secure an optimum field distribution of light wave by statistically averaging multiple reflections, a plurality of reflection points of the waveguide structure (2) may be arranged on the sliced terminals of the light-emitting semiconductor unit (1) to increase some more interfaces (23) for outputting light waves.

[0036] With reference to a preferred third embodiment of the present invention shown in fig. 3, a V-type deflection angle is formed in the waveguide structure (2) of the light-emitting semiconductor unit (1), in which a interface (23) is formed on a cleaved facet of the light-emitting semiconductor unit (1) at the V deflection point. Here, since the refractive index of the waveguide structure (2) is greater than that of the surrounding light-emitting semiconductor unit (1), the phenomenon of total (or approaching total) internal reflection of incident light waves is liable to happen at the deflection point on the bottom of the waveguide structure (2). Moreover, in the same figure, two interfaces (23) of the waveguide structure (2) in V-formation for outputting light waves could be formed on the same cleaved facet of the light-emitting semiconductor unit (1).

[0037] As the inclined angle between the waveguide structure (2) and the normal of an interface (23) for output is limited under 90°, hence, the inclined angle between the waveguide structure (2) and the normal of a interface (23) for reflection should not exceed 45°, preferably in the range of 3-40° when practical space arrangement is put into consideration.

[0038] Referring to a fourth embodiment of the present invention shown in fig. 4, an N-type deflection formation of the waveguide structure (2) includes two interfaces (23) formed at an upper and a lower cleaved facet of the light-emitting semiconductor unit (1) respectively. Since the refractive index of the waveguide

structure (2) is greater than that of the light-emitting semiconductor unit (1), the phenomenon of total (or approaching total) internal reflection of incident light waves is liable to happen at the deflection points of the N-type deflection formation should the deflection angle be large enough. Furthermore, two interfaces (23) of the waveguide structure (2) for outputting light waves could be formed on respective different cleaved facets of the light-emitting semiconductor (1).

**[0039]** Two lateral segments of the waveguide structure (2) in the light-emitting semiconductor unit (1) shown in fig. 4 are parallel with each other, and the inclined angle defined by the middle segment of the waveguide structure (2) and the normal of the interface (23) is the double of that defined by each lateral segment of the waveguide structure (2) and the normal of the interface (23).

**[0040]** Fig. 5 shows a schematic cutaway section of a fifth embodiment of the high-power semiconductor laser of the present invention. As shown in fig. 5, the waveguide structure (2) in the light-emitting semiconductor unit (1) is a W-type deflection formation, in which a interface (23) is formed at the intersection between each of three deflection points of the deflection formation and each cleaved facet of the light-emitting semiconductor unit (1). Now, Since the refractive index of the waveguide structure (2) is greater than that of the light-emitting semiconductor unit (1), the phenomenon of total (or approaching total) internal reflection of incident light waves is liable to happen at the deflection points of the W-type deflection formation should the deflection angle be large enough. Furthermore, two interfaces (23) of the waveguide structure (2) in W-formation for outputting light waves could be formed on the same cleaved facet of the light-emitting semiconductor (1).

**[0041]** Fig. 6 shows a schematic cutaway section of a sixth embodiment of the high-power semiconductor laser of the present invention. As shown in fig. 6, a deflection formation having three deflection points is provided to the waveguide structure (2) of the light-emitting semiconductor unit (1), in which a interface (23) is formed on a cleaved facet of the light-emitting semiconductor unit (1) at the second deflection point. Since the refractive index of the waveguide structure (2) is greater than that of the light-emitting semiconductor unit (1), therefore, the phenomenon of total (or approaching total) internal reflection of incident light waves is liable to happen at the deflection points should the deflection angle be large enough. Furthermore, two interfaces (23) of the waveguide structure (2) having three

deflection points for outputting light waves could be formed on the same cleaved facet of the light-emitting semiconductor (1).

**[0042]** Fig. 7 shows a schematic cutaway section of a seventh embodiment of the high-power semiconductor laser of the present invention. As shown in fig. 7, the waveguide structure (2) in the light-emitting semiconductor unit (1) is an  $\alpha$ -type deflection formation, in which the path thereof is extended from a cleaved facet to the other of the light-emitting semiconductor unit (1) to create a deflection point and a interface (23); then it is extended farther towards the original cleaved facet of the light-emitting semiconductor unit (1) to form another deflection point and subsequently, on the original cleaved facet, yet another deflection point and interface (23); then the path is reflected to go back towards the other cleaved facet to form yet another deflection point en route and another interface (23) at an intersection with the other cleaved facet of the light-emitting semiconductor unit (1). Now, Since the refractive index of the waveguide structure (2) is greater than that of the light-emitting semiconductor unit (1), the phenomenon of total (or approaching total) internal reflection of incident light waves is liable to happen at the deflection points should the  $\alpha$ -type deflection angle be large enough. Furthermore, two interfaces (23) of the waveguide structure (2) in  $\alpha$ -formation for outputting light waves could be formed on different cleaved facets of the light-emitting semiconductor (1).

**[0043]** An eighth embodiment shown in fig. 8 is another example for increasing amount of the interface (23) on cleaved facet of the waveguide structure (2) for outputting light waves. In fig. 8, the waveguide structure (2) in the light-emitting semiconductor unit (1) is an X-type deflection formation, in which each of three deflection points forms a interface (23) on respective cleaved facets of the light-emitting semiconductor unit (1). Since the refractive index of the waveguide structure (2) is greater than that of the light-emitting semiconductor unit (1), the phenomenon of total (or approaching total) internal reflection of incident light waves is liable to happen at the deflection points should the deflection angle of the X-type deflection formation be large enough. Furthermore, two interfaces (23) of the waveguide structure (2) in X-formation for outputting light waves could be formed on the same cleaved facet of the light-emitting semiconductor (1).

**[0044]** In foregoing structure of semiconductor laser, there are options for the width of a practical waveguide structure (2) for deciding a far-field distribution angle.

Also, there are options for the length and oblique angle of the waveguide structure (2). However, the selection is dependent on a selected width so as to achieve the multi-reflection purpose and oscillation of light wave on and among the reflective surfaces (22).

[0045] Moreover, as illustrated in fig. 9, in order to secure a better reflection effect of the reflective surface (22), the waveguide (21) of the waveguide structure (2) is constructed in a ridge or buried-hetero structure.

[0046] In the ridge-structured waveguide (21), two sides of the ridge are etched to a lower level than the ridge structure itself, and the etched depth is limited to 200nm above or below an active layer (25).

[0047] The refractive index of the waveguide structure is larger than that of the light-emitting semiconductor unit (1).

[0048] A broad width, particularly 10 $\mu$ m up, is adopted for the waveguide (21) of the waveguide structure (2). [0049] In foregoing structure of semiconductor laser, an interface (23) may be formed on a broken interface of crystal boundaries of the semiconductor or by dry etching.

[0050] Besides, the interface (23) may be coated for high reflectivity.

[0051] As illustrated in Fig. 10, in foregoing structure of semiconductor laser, there is at least a interface (23) connecting to an external-cavity configuration (24) composed of a mirror surface (24a) and a lens (24b) such that a light beam is allowed to penetrate through the interface (23), then project on the lens (24b) of the external-cavity configuration (24) to reach the mirror surface (24a) and reflect back into the waveguide structure (2) of the light-emitting semiconductor unit (1) along the original path.

[0051] Here, the high-power semiconductor laser of the present invention is to be proven that its output power can reach that of the diffraction limit through a first embodiment of a high-power semiconductor laser manufactured by way of a generic semiconductor fabricating process, in which the inclined angle contained by the waveguide structure (2) and a interface (23) is about 7°, and the waveguide of the waveguide structure is ridge-structured. The conclusions of the present invention may be summarized as the following:

[0052] (1) The relationship between light power and current of the high-power semiconductor laser of the present invention shown in fig. 11 is about the same compared with that of a generic semiconductor laser.

[0053] (2) The far field of light before resonance of the high-power semiconductor laser of the present invention is shown in fig. 12.

[0054] (3) The spectral distribution is rather wide before resonance of the high-power semiconductor laser of the present invention as shown in fig. 13.

[0055] (4) As shown in fig. 14, after resonance, the gain of the semiconductor laser of the present invention is boosted to drive light to propagate along the dotted lines shown in fig. 1 and resonated between two mirror surfaces, where the far-field distribution angle is about 5°.

[0056] (5) After resonance, the spectral distribution of the semiconductor laser of the present invention is relatively narrow as shown in fig. 15.

[0057] (6) As shown in fig. 16, after resonance of the semiconductor laser of the present invention and when a light beam of a interface (23) is fed back into the waveguide structure (2) by an external-cavity configuration for example, the light intensity from another interface will be boosted as high as 2W in this case.

[0058] (7) As shown in fig. 17, after resonance, the far-field distribution angle is narrowed to 0.7° approximately when a light beam of a interface (23) is fed back into the waveguide structure (2). The near field shown in fig. 18 corresponding to the far field reveals a diffraction limit according to optical principles. The feedback light is supposed to enhance the resonance along the dotted lines shown in fig. 1 to thereby boost the power to achieve the diffraction limit. Also, the reflectivity of the interface (23) may be heightened by coating a plated film thereon.

[0059] In the above described, the preferred embodiments have been described in detail with reference to the drawings annexed, and it is apparent that numerous changes or modifications may be made without departing from the true spirit and scope thereof, as set forth in the claims below.